NC PAINTING ROBOT FOR SHIPBUILDING

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1. Introduction

So far, the automation of production in Japanese shipyards has been focused on the cutting & welding activities and it has greatly contributed to the improvement of productivity or quality. Especially the popularization of NC cutting machines has promoted not only “Hardware” effect(rationalization like unmanned operation of marking and cutting activities) but also “Software” effect(innovative advancement of supporting system technology to operate the machine effectively). Namely, it played a role of explosive energy to promote remarkable improvements of whole shipbuilding activities such as manufacturing method, production system and management. In particular, it is remarkable that the improvement of dimensional accuracy by NC cutting contributed to the improvement of manufacturing method at the subsequent progress of work.

By the way, Figure 1 shows the composition of number of workers by discipline in the shipyard. It shall be noted that the percentage of painters is equal to one of welders and the both activities are currently 23% of the total number respectively. Even if we automate only welding activity, the total cost saving effect is small in the whole shipbuilding activities. Japanese shipyards are now living in the times when the approach to automation for painting and fitting can not be bypassed because they also show the large percentage for the total man-hour. Especially the painting cost is rapidly increasing due to the shortage of painters. Furthermore, the paint area has remarkably increased due to the application of double hull structure to VLCC based on the IMO/MEPC requirement(1.5 times of single hull). Therefore, automation of painting activity is the most urgent development subject in the shipyard. Depending on these background, the authors have started the development of NC painting robot for

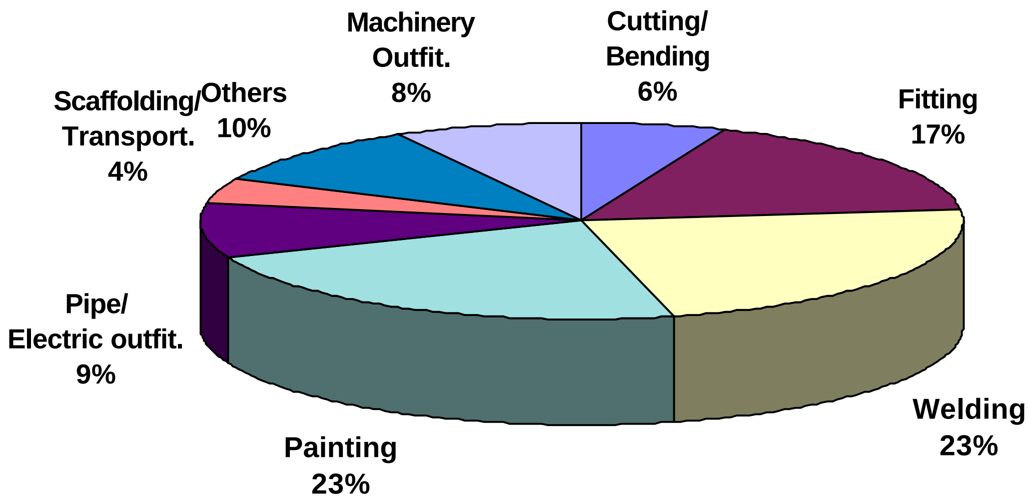

Figure 1 Composition of Number of Workers by Discipline

shipbuilding since 1991 and recently succeeded in the development of a unique robot, which enables to realize automatic painting in the water ballast tank of closed double hull blocks. The developed robot has been applied for the production of VLCC. This paper reports the outline of developed robot and the application status for the production of double hull VLCC.

2. Development History

Figure 2 shows our development target on the application scope of painting robot for a double hull VLCC(307,000 DWT type). The area to be painted of a VLCC is total 390,000 m^2. About 60% of it has been painted on land(including painting shop) and the remained 40% has been painted in dock. Automation for the all is unrealistic in terms of economical and technical points of view. Based on a fundamental concept that just the bad working environment where human dislikes shall be automated, the authors tried an approach of automation for the painting activity inside water ballast tank(WBT) of double hull structure.

The development of painting robot for shipbuilding is regarded as a highly developed production technology which requires a concentration of potentials of global technologies such as CAD/CAM, robots, IT and ship-design/building, etc. and there are no president in the history of shipbuilding worldwide. Metaphorically speaking to the development of submarine oil field, the authors are in the stage that we have just started the real mining of crude oil finding a hopeful oil field at last after repeating trial digging for a long period.

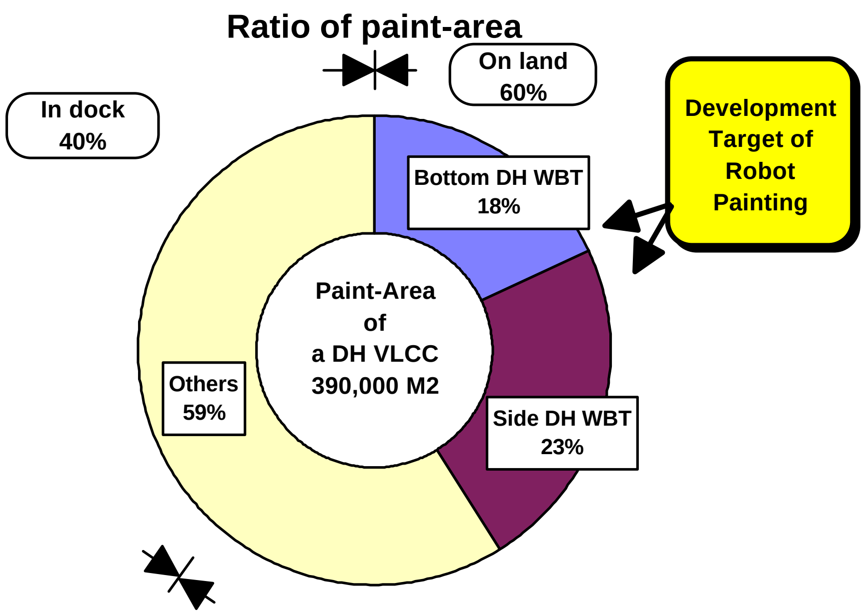

Figure 2 Application Scope of Painting Robot for a Double Hull VLCC

The development has been promoted dividing into two steps. The 1st step development is based on an application concept of painting robot for the opened double hull unit block with the dimensions of max. 25m length and max. 14m width. After turning over of a block, the robot approaches upward to the block as shown in Figure 3. The painting robot system consists of a CAM system linked with 3D CAD system, a controller, an automatic painting machine, and a robot main body. The robot main body consists of a unique placer with 3 axes freedom utilizing a λ type link-mechanism and a compact manipulator with 6 axes freedom. A prototype robot was developed and the feasibility study of robot painting for shipbuilding was carried out [1]. But through the 1st step study, the authors got a conclusion, namely it is difficult for us to find economical merit in case of the application for the opened double hull unit block because the applicable area of robot painting is obliged to be limited in order to avoid the damage by welding of subsequent stage.

So, changing the application concept of robot, the authors have started the 2nd step development since 1996. The 2nd step development is a challenge of real automation for the closed double hull block, whose grand assembly and outfitting activities have been completed. According to this concept, as a matter of course, the block to be painted is the structure consisting of some divisions closed up from all directions and also all outfitting parts have been already fitted to the block. Compared with the application concept of 1st step, the technical difficulty increased remarkably. For instance, how shall we bring in the robot for the closed huge block ? How shall we let the robot move autonomously in the block ? And, how shall we avoid the interference between the robot and structural members including outfitting parts ?, and so on. Although there were so many subjects to be broken through, a confidence with tenacity might have led us to a success of development. (namely, we will be sure to succeed in the development provided that we could concentrate our global technical potentials cultivated until now.)

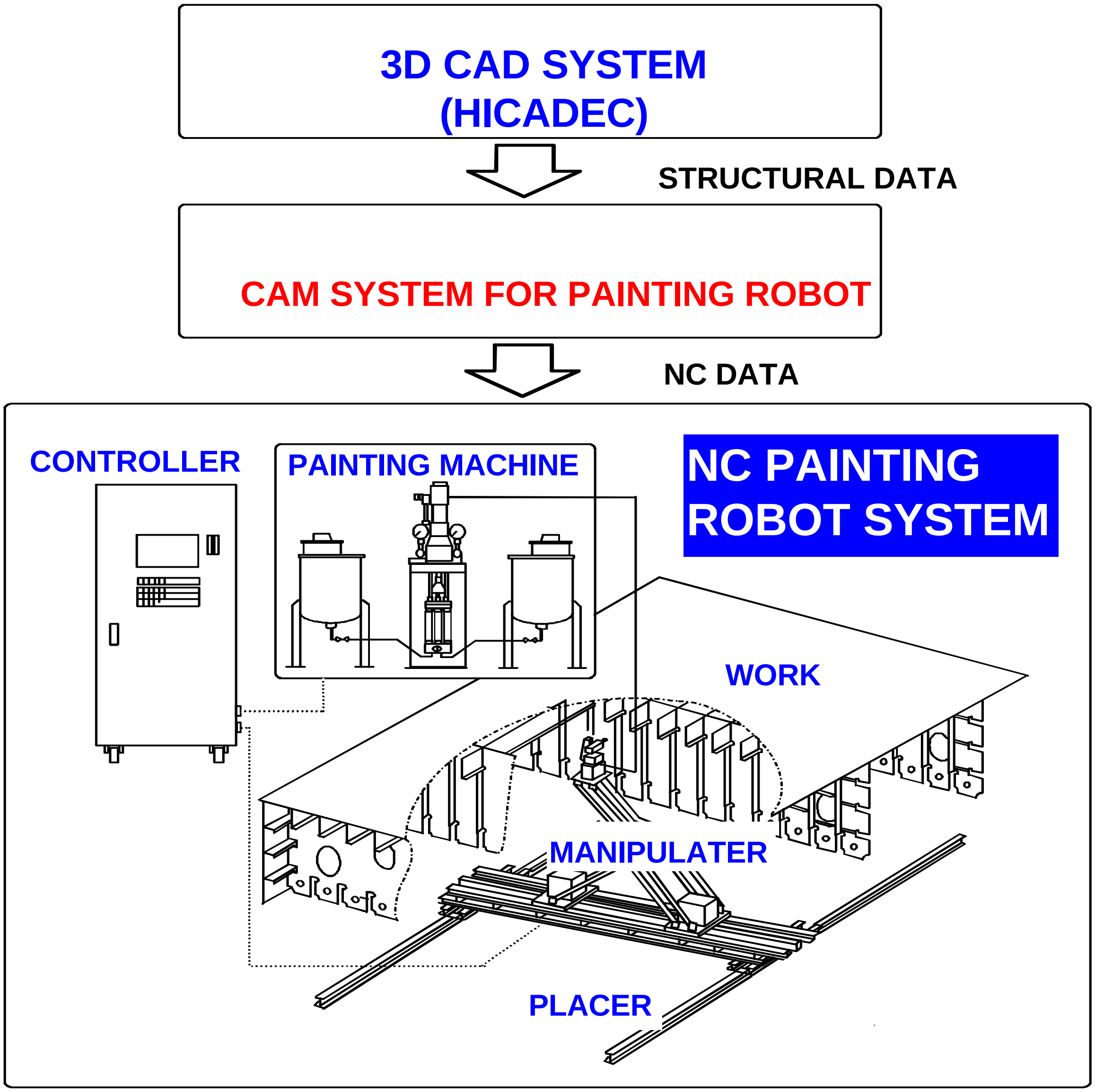

Figure 3 Application Style of Painting Robot for Opened Double Hull Unit Block

3. Painting Robot for Closed Double Hull Block

3.1 Application Concept

In case of the authors' shipyard, the double hull block of VLCC is gland assembled as a huge cubic block with 20m length, 30m width, 8m height, and the weight is approx. 650tons. In order to automate the painting activity of closed tank of such huge block, the authors devised a unique application concept of painting robot with following features: a)Use of self-driving type portable NC robots which enable to run on the face plate of longitudinal frames without rail. b)Each floor shall have a permanent opening (with the dimensions of approx. 800mm x 1,600mm) for passing through of robot in the structural design. c)High adaptability for current ship production system since plural robots are optionally applicable to the block anywhere. d)Investment scale of facility is very small, and nearly 100% robot painting is geometrically possible for the inside tank of closed double hull block. e)Operation linkage between CAD/CAM and robot systems is possible in the shipyard CIM environment.

Figure 4 shows the schematic explanation of necessary consideration on the structural design of ship. Using the structural analysis program of classification society, the optimum location of permanent opening for the floor and/or the suitable stiffening method are discussed and reflected into the structural design of ship.

Figure 5 shows the transportation method of painting robots. The robot painting is carried out shifting a trailer mounted two sets of painting robot system from stage to stage. Two robots are operated by single operator.

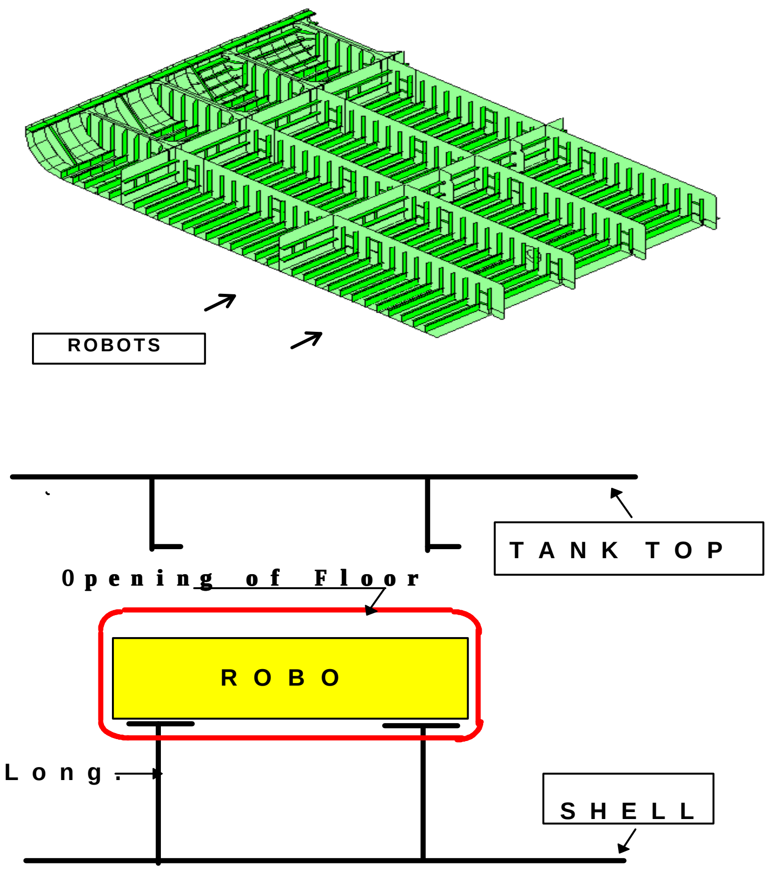

Figure 4 Necessary Consideration on Structural Design

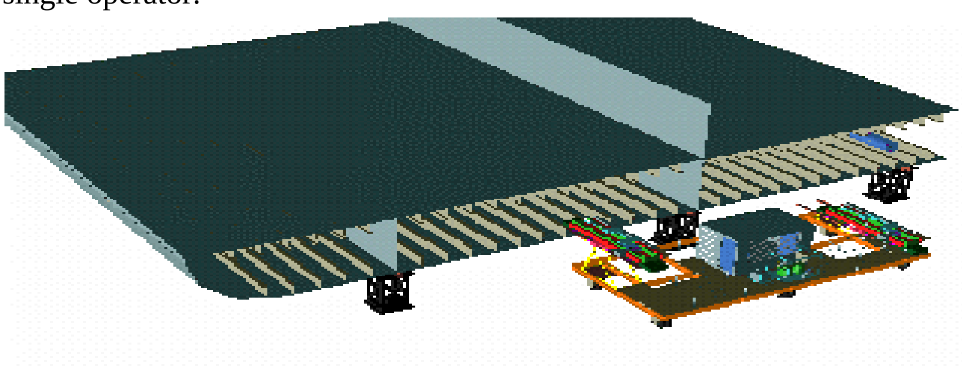

Figure 5 Transportation Method of Painting Robots

3.2 Hardware

3.2.1 Robot Main Body

The robot main body consists of a self-driving carriage, an external axes placer and a manipulator. When the robot enters into the block or passes through the opening of floor, the placer and the manipulator keep the most shrunk posture on the carriage as shown in Figure 6. The movement of robot main body and the automatic painting machine are perfectly controlled by NC data. The robot main body moves from the most inner division toward this side sequentially painting each division. Figure 7 shows the image of robot painting in the double hull tank.

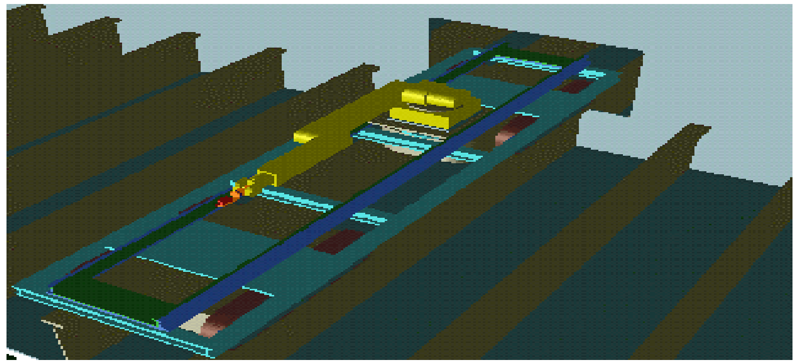

Figure 6 Robot passing through the Opening of Floor

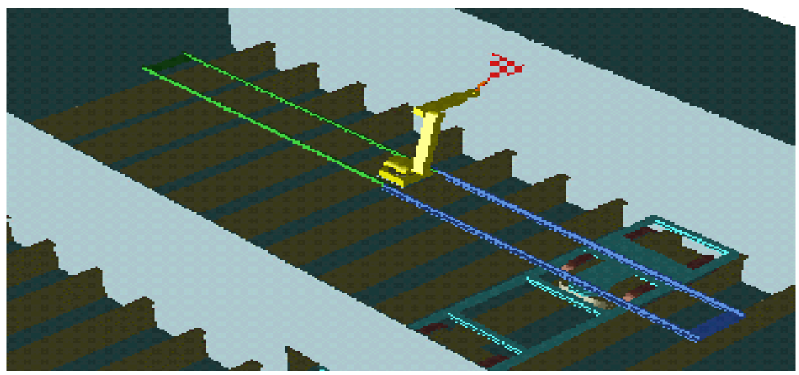

Figure 7 Image of Robot Painting in the Double Hull Tank

Manipulator: Articulated type manipulator with six axes freedom is very compact and light weight design. In case of the most shrunk posture, the manipulator can keep 300mm in height. On the other hand, it has sufficient movement range for the painting of double hull tank with about 3m in depth. Since the manipulator has been designed as a unique shape with long arm, the arm of cylindrical shape has been used in order to keep the necessary stiffness. "In-line type" manipulator as shown in Figure 8 is also one of highlighted features. Namely, the paint is supplied through inside manipulator in order to avoid the damage of painted surface due to the handling of hose. It is a mandatory function for the painting robot for shipbuilding to be operated in the very narrow space. Regarding the countermeasure for explosion, internal air pressure type has been used.

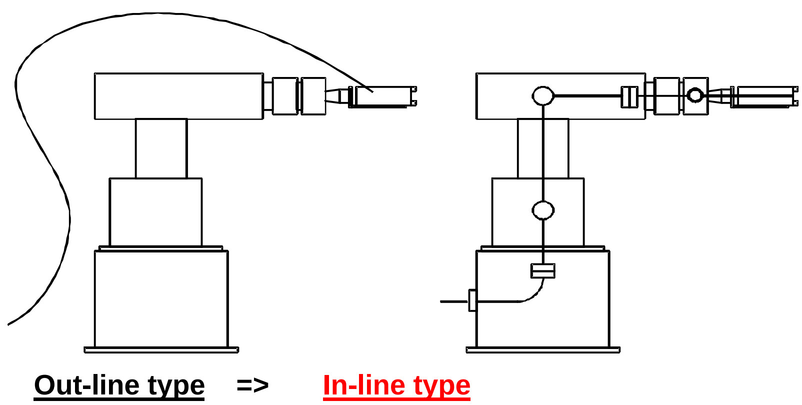

Figure 8 In-line Type Manipulator

Placer: The role of placer is to move an origin of manipulator to the suitable location in a division surrounded by floors and girders. It is the external control axes of two steps telescope mechanism with five axes freedom as shown in Figure 9.

Self-driving carriage: The self-driving carriage mounts the above mentioned placer and manipulator, and it runs on the faces of two longitudinal frames without rails by utilizing two sets of magnetic crawlers.

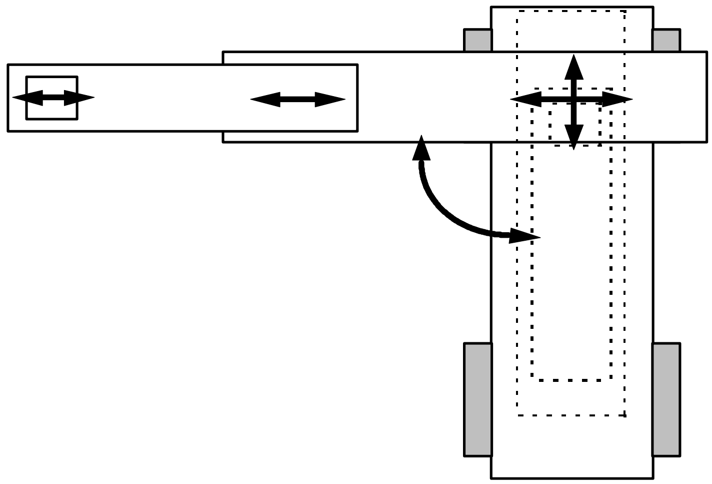

Figure 9 Freedom of Placer

3.2.2 Controller

A PC-based controller has been developed, whose CPU is Intel Pentium 150MHz, OS is Windows NT, and it uses an object oriented control method considering the performances of high speed processing and possibility of extension.

3.2.3 Automatic Painting Machine

Two liquids mixture type paint(Tar-Epoxy) is used for the water ballast tank of double hull. The base material and the hardener are homogeneously mixed by the automatic painting machine and airless sprayed. The start/end of painting are controlled by NC data depending on the instruction from the controller.

3.3 Software

The CAM system for painting robot (so called CAMEX-Paint) automatically generates the movement data of robot based on the structural data output from the CAD system (HICADEC-H) [2] and the outfitting data output from the product model (PHI) [3] or by manual input as shown in Figure 10. And it outputs the NC data, the application plan and the management data. The specifications of painting and

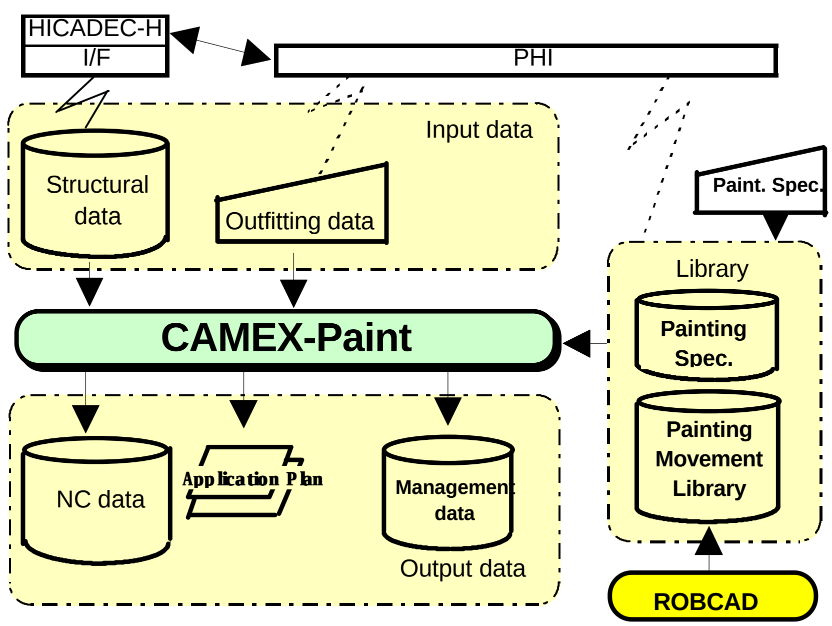

Figure 10 CAM System for Painting Robot

the painting library has been preliminary prepared and they are referred in the process of CAM system and incorporated in the NC data. Furthermore, a simulation system of painting robot utilizing the ROBCAD has been also developed in order to support the operation. It has been used for the purposes of the interference check between robot and work and the preliminary simulation of coating thickness of paint.

3.3.1 CAMEX-Paint

The CAM system for painting robot has been developed in the environment of Pentium PC, Windows-95, and Borland C++ Builder using the software technologies which the authors' have cultivated in the field of welding robot up to now. Namely, an object library so called CCL(CAMEX Common Library) was utilized considering the efficiency of development and the performance of maintenance, which the authors' had been already developed for the CAM system of welding robots [4]. Figure 11 shows the CCL data structure for painting robot. The part of "Structure" is just the same to one of welding robot and the parts of "Recognized structure" and "Movement" were newly extended for the painting robot.

Input data: Input data consists of structural data and outfitting data. The structural data has been expressed by IGES format composed by geometric data of structural parts and the attributes such as ship no., block name, and parts name, all of which are sent via an interface(I/F) [5] from HICADEC-H. On the other hand, the authors are currently difficult to get the correct shape of the outfitting inside double hull tank such as ballast pipes, anodes, steps, and grips, etc. since the full application of outfitting CAD system and product model have not been realized yet. Therefore, the outfitting data has been used for only the purpose of interference check by inputting the locations and the outline dimensions of them. They have not been painted by the robot.

Output data: Output data consists of movement data, application plan, and management data. The movement data of robot and the pattern data of painting are output to the file. All movements of the self-driving carriage, the placer, the manipulator, the start/end of painting are controlled by the NC data. The application plan includes following items: a)Name of NC data, PROG No., & JOB No., b)Structural information of work(ship No., block name, wing or center tank), c)Drawing of painting area, d)Drawing of area to be reserved painting. The management data includes following items:

a) Area subject to painting(m^2) : Total area to be painted.
b) Actual painted area(m^2) : Total area of actual painted element surfaces.
c) Reserved area of painting(m^2) : a - b
d) Ratio of reserved area(%) : c / a * 100
e) Painting time(min.) : Distance of painting * Velocity
f) Air cut time(min.) : Distance of air cut * Velocity
g) Operation time(min.) : e + f
h) Consumed paint(l) : e * spraying velocity

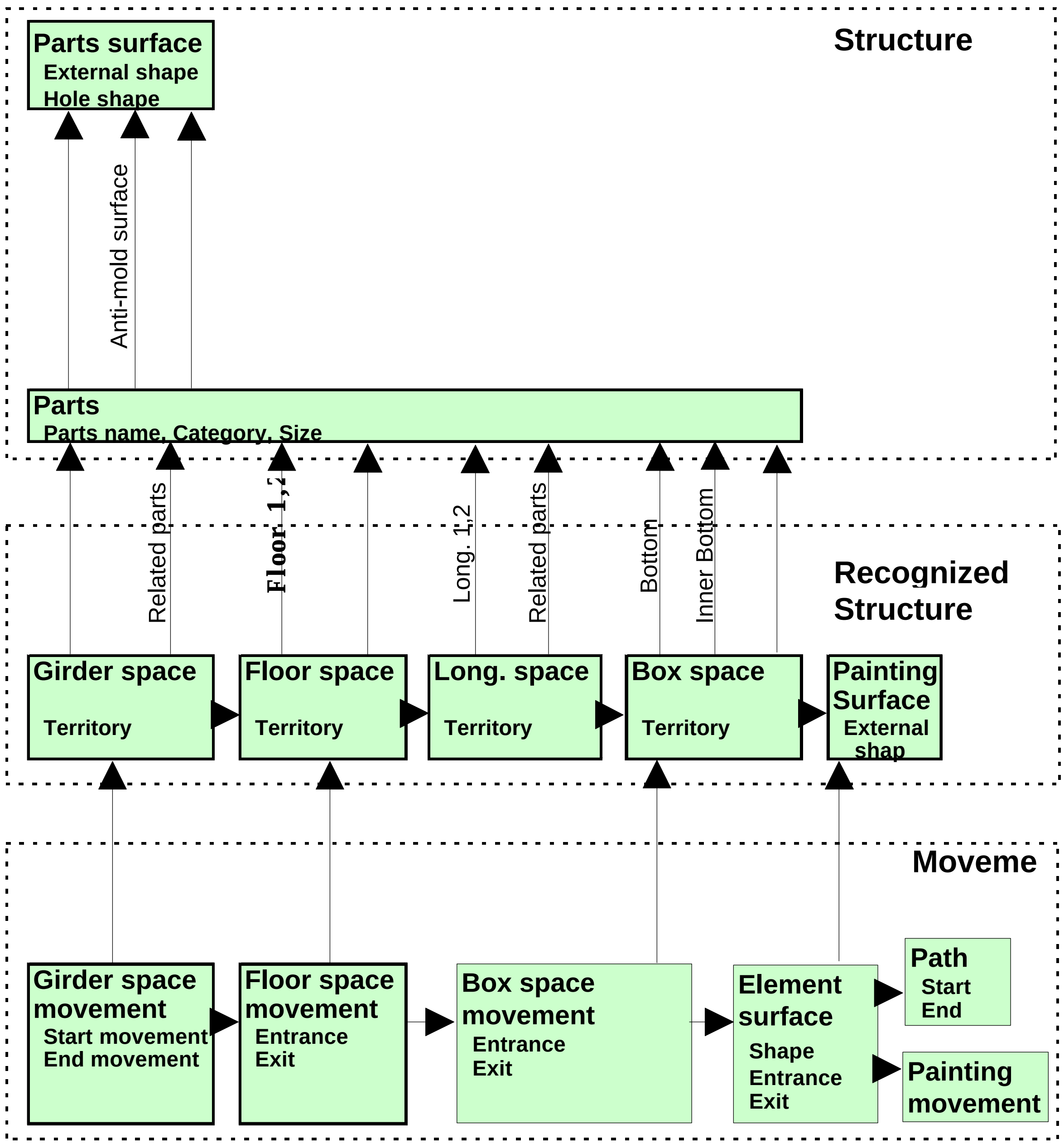

Figure 11 CCL Data Structure for Painting Robot

Library: The library consists of painting specifications and painting movement library. The painting specifications are the necessary information of spray painting to be selected for each block. Following items are included: a)Name of painting condition, b)Coating thickness, c)Number of layer, d)Name of paint, e)Coating thickness of dried condition, f)Secondary pressure, g)Chip No., h)Spray distance, i)Pattern width, j)Painting velocity, k)Accelerated velocity of painting start, l)Accelerated velocity of painting end. The painting movement library is the necessary information of spraying technique for the robot, and it has been preliminary set to be able to automatically pick up.

Generation process of robot movement data:

The hull structure sent from HICADEC-H is recognized dividing into the girder space, the floor space, the long. space, and the box space. For the each space, the robot movement data is generated. The girder space is a division divided by two girders as shown in Figure 12. In case that a water tight bulkhead (W.T.B) exists in a block, the girder space is further divided by it. One girder space corresponds to PROG of NC data and it is a unit of continuous movement for painting robot. The floor space is a division divided by the floor within the girder space. The robot performs painting sequentially from the most inner floor space toward this side. The box space is a division which enables to paint by the movement of only the manipulator or the placer. Figure 13 shows the typical patterns of box space. For the each pattern, the robot movement pattern has been preliminary prepared, and actual movement data is automatically generated depending on the dimensions of composed members.

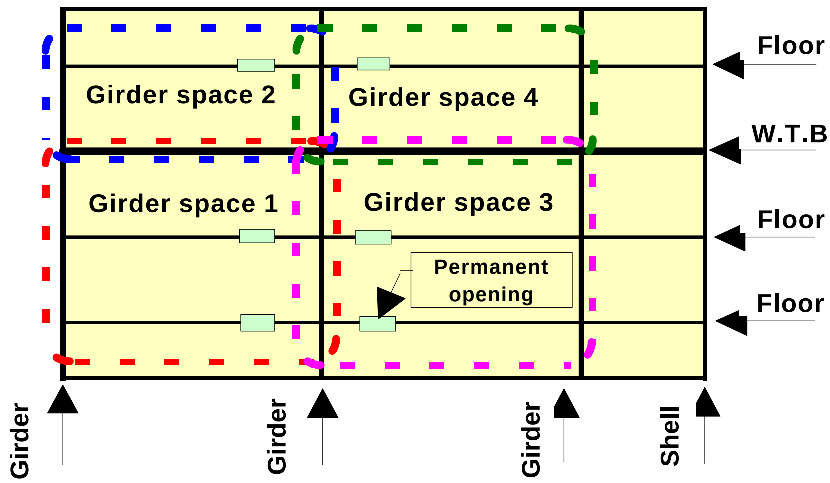

Figure12 Girder Space

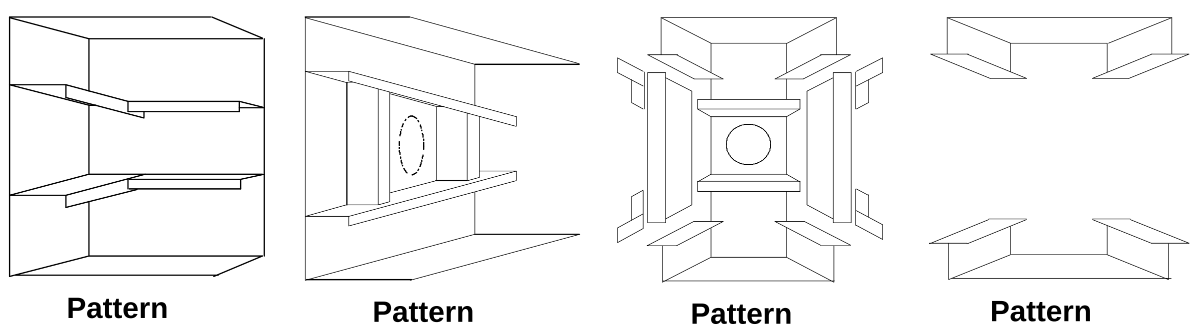

Figure 13 Patterns for Box Space

3.3.2 Painting Robot Simulation System

Utilizing a software on the market so called ROBCAD, the authors have developed a simulation system for painting robot in order to support the operation. The development has been carried out in the environment of Silicon Graphics Indigo2 R4400 Solid impact/IRIX V5.3, ROBCAD V3.5/DCM/ Paint-Master, G^{++}. Figure 14 shows the outline of simulation system. It has been effectively utilized adding the following functions to the ROBCAD system: a)Interface to generate hull surface model automatically from HICADEC-IGES data(CAD I/F), b)Interface to supply the NC data output from CAMEX-Paint to the robot model within ROBCAD(Upload I/F), c)Interface to perform the simulation based on movement mode(Simulation I/F), d)Interface to output the NC data of amended movement(Download I/F). Figure 15 shows an example of simulation screen of robot painting. It is a very useful supporting system for the operation of robot, since it is effective not only for the discussion of optimum robot movement but also for the avoidance of trouble due to visual interference check and/or for the simulation of coating thickness of paint.

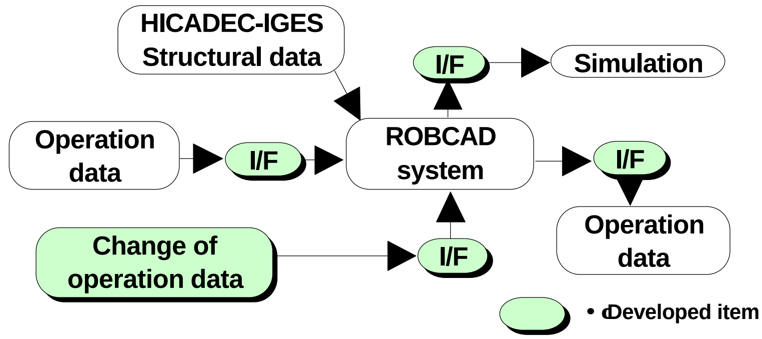

Figure 14 Simulation System for Painting Robot

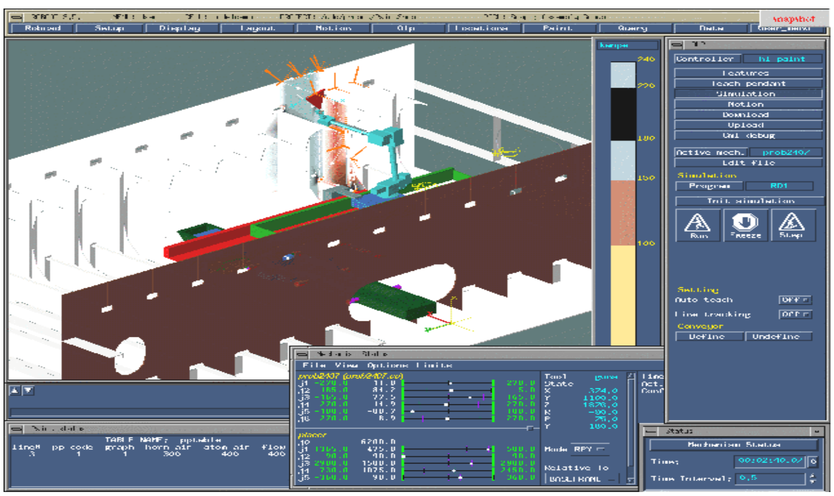

Figure 15 Simulation Screen of Robot Painting

4. Application to VLCC

The application of developed robot was tried for the building of 307,000 DWT type VLCC in June 1998 in the authors' shipyard. The applied block is the wing tanks of double bottom. Figure 16 shows the plan of applied structure, the possible area of robot painting, the impossible area due to geometric reason, and the actual applied area of robot painting. Table 1 shows the painting condition. The painting robot was applied in combination with a manual airless spray machine in lieu of automatic painting machine due to the unexpected trouble in this trial.

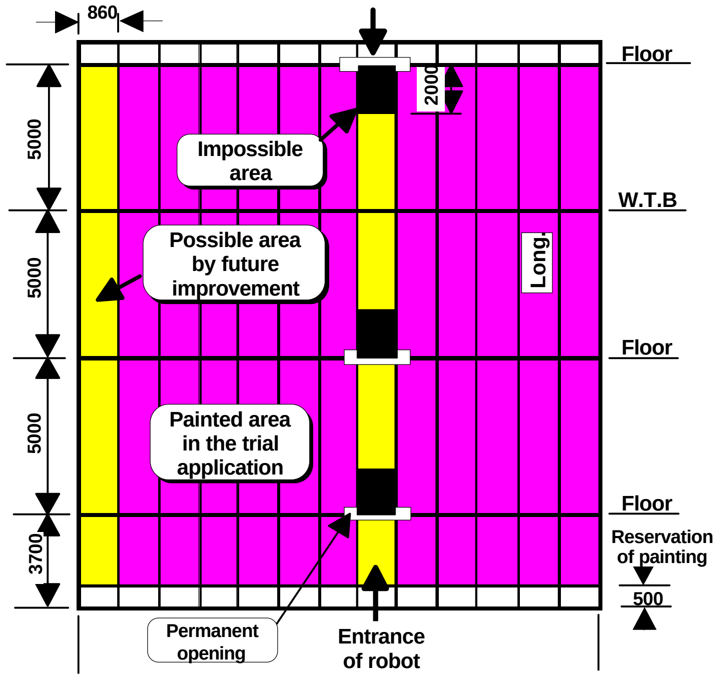

Figure16 Applied Structure of Painting Robot

Table.1 Painting Condition

Place	In painting shop
Atomospheric temp.	29 degree C
Moisture	70%
Painting machine	Airless spray machine
Brand of paint	Eposeal No.6000PS black
Coating thickness	250 micron (dry)
Heating	None
Mixing ratio of sinner	3%
Temp. of paint	28 degree C
Viscosity of paint	18 ps
Chip	623
Filter	60 mesh
Spray pressure	1st: 2.5 kgf/cm2
	2nd: 150 kgf/cm2
Velocity of painting	180 mm/sec.
Spray distance	400 mm

Figure 17 shows the painting robot entering into the block, Figure 18 shows the robot passing through the permanent opening of floor, and Figure 19 shows the status of robot painting in the closed double hull tank. Through the application to actual ship, it was confirmed that the painting robot has the sufficient durability and reliability for the continuous operation of long time. Human painter makes a effort to keep the homogeneous coating thickness by crosswise lap painting technique, and he carries out painting in accordance with a sequence: at first for the ceiling(overhead posture), secondary for the wall(vertical posture), and finally for the floor(flat posture) after cleaning the dropped dust on it. On the other hand, in case of robot, the specified coating thickness is available by single layer painting technique lapping the pattern width. Therefore, the robot painting enables a continuous painting with the sequence from the floor to the ceiling via the wall. Because the dust made during painting of the wall and the ceiling adheres on the correctly coated

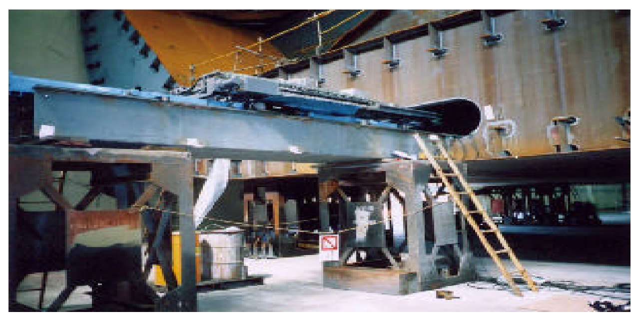

Figure 17 Approach of Robot to Block

Figure 18 Robot passing through the Floor

Figure 19 Robot Painting in the Closed Double Hull Tank

surface and it does not give any bad effect for the quality of painting.

Table 2 shows the actual data and future possibility of robot painting. Division by division, robot painting was carried out trying the improvement of software such as reduction of air cut time. Although the robot painting was applied for 75% of subject painting area in the trial application, the authors had a confidence that about 99% of subject painting area could be automated by the future improvement of application software. And the authors also has a confidence that the standard time of robot painting could be improved further 30 ~ 40% from one of trial application($0.027H/m^2$) by the improvement of software. By the way, as a matter of course, the touch up for robot painting is necessary for the corner edges of drain hole or scallop like the case of human painting. Therefore, it will be the reasonable understanding that the efficiency of a robot corresponds to one of a skilled painter. The cost saving effect will depend upon the applying method of plural robots for a block. According to the authors' idea, 4 robots for a block could be simultaneously operated by 2 operators. Regarding the quality of robot painting, the specified coating thickness without any harmful defects was given for the all painting postures. And the consumed quantity of paint was same to one of human painting. Based on the successful application to actual ship, the authors' shipyard intends to positively promote the real automation of painting activity in shipbuilding.

Table 2. Actual Data and Future Possibility of Robot

Division	Subject painting area (m^2)	Actual result of robot application				Future possibility of robot		
		painting area (m^2)	Consumption of paint (Kg)	Painting time (H)	Standard time (H/m^2)	painting area (m^2)	Consumption of paint (Kg)	Painting time(H)
No.1	390.7	335.6	240	9.93	0.030	358.9	280	6.95
No.2	419.9	305.6	220	7.65	0.025	415.1	300	7.47
No.3	388.1	332.9	260	8.62	0.026	383.3	300	6.90
No.4	244.4	101.7	100	2.57	0.025	244.4	240	4.40
Total	1443.1	1075.8	820	28.77	0.027	1428.7	1120	25.72
Ratio of area		75%				99%		

5. Concluding Remarks

This paper reported about the development of NC painting robot for shipbuilding which enables automatic painting of closed double hull block. Application technology of welding robot in shipbuilding has already advanced to the level that we can forecast the “Ultimate Automation” [1] during 18 years since the start of development. On the other hand, automation of painting is still a future subject. But, according to the challenge of Hitachi Zosen Ariake Works, the real automation of painting is also close to reality.

Automation of painting is a hopeful technology in terms of cost saving in shipbuilding. But, seeing the robot working silently in the closed narrow space, it is a honest impression of the authors that “a pleasure of releasing human from the bad working environment” was by far greater rather than arguing of economical effect.

Painting robot technology is expanding in its importance as a part of new generation shipbuilding research, and it will be essential for modernization of shipyards which utilize to a maximum extent of highly sophisticated production system.

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